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Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

CANADIAN RESEARCH, DEVELOPMENT AND DEMONSTRATION ACTIVITIES IN COAL GASIFICATION, COAL LIQUEFACTION AND COAL OIL MIXTURE COMBUSTION.

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NOVEMBER 1979

THIS REPORT HAS BEEN PREPARED FOR USE AT THE JOINT CHINA-CANADA SEMINAR ON ATMOSPHERIC POLLUTION CONTROL PERKING, CHINA, NOVEMBER 20-30, 1979

ENERGY RESEARCH LABORATORIES
ENERGY RESEARCH PROGRAM
ERP/ERL 79-52 (TR)

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INTRODUCTION

A major target for the Canadian energy industries is to overcome our growing dependence upon imported oil. The Department of Energy, Mines and Resources, in it's "Energy Strategy for Canada - 1976", set a target for keeping net oil imports to a maximum of one third of the domestic market or 800,000 barrels a day, whichever is lower.

In addition to the possibilities of new oil supplies from Canada's frontier region, the accelerated development of the oil sands and heavy oils of Alberta and Saskatchewan, a higher extraction rate of natural gas from the established producing regions and the expanded nuclear generation of electricity to meet this target; Canada also has the option of developing the technology to increase the utilization of its large coal reserves.

COAL RESERVES

The 1976 estimate of coal reserves in Canada was 28,940 million tonnes (proven) and 164,663 million tonnes (inferred). These figures should be considered as present established values which will no doubt increase as more information becomes available.

The 1977 coal production in Canada was about 29 million tonnes, while coal consumption was about 30 million tonnes (making Canada a net importer of coal).

Investigations indicate that the optimum size for commercial gasifying plants producing substitute natural gas from a coal feed, is about 8 million cubic meters of gas per day. A plant of this size would require at least 5 million tonnes of bituminous coal per year and over a normal plant life of 30 years, 150 to 300 million tonnes of coal (depending on rank and quality) would be required.

In order to formulate a coal alternative answer to Canada's future energy requirements, the Department of Energy, Mines and Resources have suggested five strategy categories. These are:

1. The development of high-performance coal-to-electricity processes, such as gasification-combined cycle as applied to the low-rank coals of Western Canada.
2. The substitution of coal for imported oil in Eastern Canada, chiefly by utilities and industries by using coal-in-oil technologies.
3. The use of coal in the production of fuels for transportation by (a) utilizing coal in heavy oil and oil sands processing to maximize oil yields as well as (b) the direct production of liquids from coal.
4. The use of coal in utilities and industry for such related purposes as in co-generation and in district heating schemes.
5. The production of substitute natural gas from coal, and the related technologies of methane drainage from coal seams and underground gasification of coal (in-situ gasification).

IN HOUSE GASIFICATION FACILITIES

In support of the studies on low and medium energy gasification processes, the Canada Centre for Mineral and Energy Technology (CANMET), Department of Energy, Mines and Resources, is establishing an experimental facility to evaluate Canadian coals. This facility includes:

1. a fixed bed gasifier, capable of operating at atmospheric pressures up to a maximum temperature of 1200^{o}C and a maximum reactor charge of 10 kg.
2. a thermobalance reactor, designed to operate at maximum conditions of 2500 psi and 1000^{o}C, using small coal samples and,
3. a continuous gasifier, designed to operate at conditions of 2500 psi and 1000^{o}C, treating 150 g/min of coal.

This equipment will be used to determine the kinetic rates, product qualities and yields from pitch, bitumen, oil and coal under a range of conditions, either in the fixed, fluidized or entrained bed mode of gasification.

Initial tests, leading to the commissioning of the first unit, were begun in February, 1979, with the expectation that the unit would be fully operational during May 1979. The second and third experimental systems will come on stream later in the year.

The Department of Energy, Mines and Resources is also funding the construction of a laboratory fixed-bed reactor at Carleton University (Ottawa) and a "spouted-bed" reactor at the University of British Columbia. The "spouted, bed" reactor, originally invented in Canada for the gasification of caking coals, has been evaluated for coal gasification processes in Australia.

The Saskatchewan Power Corporation, with Federal support, has been conducting technical and economic studies of coal gasification based on coal deposits in the Saskatchewan area.

This project includes a review of the technology and economics for producing medium and pipeline quality gases from lignite coals, economic evaluation of the transmission and storage of these gases for use in Saskatchewan industries and utilities, and an investigation of the technical modifications necessary to make use of the medium quality gases with an evaluation of the economic effect of such modifications on the marketability of gas.

They are also conducting studies in the assessment of processes for electric power generation, using coal-gasification, combined-cycle techniques, with minimum water requirements.

In cooperation with EMR and the Alberta Department of Energy and Natural Resources, Shell Canada Resources Ltd., assessed the conversion of coal in the Edmonton/Fort Saskatchewan region of Alberta for the production of fuel gas, useful for a number of industrial applications in the region. Algas Resources Ltd., in cooperation with EMR, conducted studies on processes applicable to low rank Canadian coals which would produce marketable products such as SNG, low quality gas, hydrogen, ammonia, liquid fuels and chemical feedstocks.

The British Columbia Hydro-Electric Power Authority, with federal support, examined the possibility of using fluid-bed gasification, combined-cycle processes to produce electric power from low grade B.C. coals and coal wastes.

In the related technology of underground coal gasification and methane drainage, a series of cooperative industry-government trials of underground coal gasification has been managed by the Research Council of Alberta.

THE DEVELOPMENT OF COAL LIQUEFACTION IN CANADA

On the surface it might appear that the most prudent route for Canada to follow would be to adapt or modify technology developed elsewhere. Apart from considerations related to Canadian coals and Canadian demands, this simplistic approach ignores the need for personnel and infrastructure to commercialize the technology. If the necessary effort were made to improve our understanding of Canadian coals and of future liquid fuel requirements, and the need for expertise and infrastructure were addressed immediately, the emergence of uniquely Canadian technology would be more likely.

The other main option available to Canada is to pursue the use of coals to maximize liquid product yield from oil sands and heavy oils. This prospect deserves immediate attention, because it represents an opportunity for Canada to take the lead in a technology that may be of interest to other nations as they turn to lower-grade petroleum resources. If Canada is to participate fully in international research and information exchange, it must have something to offer, and this technology could be it.

Preferred liquefaction options

If Canada does eventually turn to coals for liquid fuels, it is far from clear what technology would be most appropriate, although some processes are now in a more advanced stage of development. Each option has its own merits in particular circumstances. The choice will ultimately be based on desired products, coal characteristics, and of course, cost.

Hydroliquefaction - The three most promising American processes, H-Coal, Solvent Refined Coal, and Exxon Donor Solvent, represent variations on the hydro-liquefaction principle. The American experience suggests that these processes deserve careful consideration as they may be commercially available before too long. Process conditions in all three can be varied depending on the products desired.

Currently there is more interest around the world in hydroliquefaction than in either pyrolysis or synthesis, principally because its higher thermal efficiency and liquid yield leads to more favourable economics and greater promise of commercialization if production of liquid fuels is the goal.

There are, however, some disadvantages to all hydroliquefaction processes. All require large quantities of hydrogen which is currently expensive. Also, handling of large quantities of slurries at high pressure has proven difficult in pilot plant studies. Separation of residual solids from

the product stream is a serious problem which is further complicated if the feed coal is high in ash. Finally, processes such as H-Coal which require a catalyst, face the problem of rapid catalyst deactivation by impurities and heavy molecules in the coal.

Hydroliquefaction processes are particularly well suited to the high-volatile bituminous coals of Nova Scotia. Recent research has also indicated that low-rank coals such as those in Saskatchewan and Alberta might be excellent feedstocks in a process that uses synthesis gas. On the other hand, high ash content in some Western Canadian coals might preclude their use in a hydroliquefaction scheme.

Pyrolysis avoids some of the principal problems associated with hydroliquefaction because hydrogen and catalysts are not necessary - although they can be added - and there is no requirement to separate solids from product slurries.

Current pyrolysis processes give low liquid yields, and have therefore not been considered leading contenders for liquid fuel production. Large quantities of solid fuel of questionable combustion quality are produced. It is possible to gasify the solid to fuel gas. In fact, char gasification has been applied to FMC Corp's COED process, thus improving substantially the economics of the process.

Process improvements are making pyrolysis more attractive. Flash hydropyrolysis might be particularly applicable in Alberta and Saskatchewan, which are turning to low-rank coals for thermal electric power generation. The process may allow production of tars and oils, while still producing a coal-derived solid fuel. Thus power plant needs would still be met, but other valuable constituents in the coal would be produced as well. From the standpoint of products, the process might also be of interest in Eastern Canada, but the agglomerating tendencies of Nova Scotia coals would create reactor problems, and the coals' high sulphur content would be largely carried over to the char.

Synthesis processes have some serious deficiencies, but do have some advantages that can be significant in particular circumstances. It is appropriate to consider first whether the technology used at SASOL in South Africa is applicable in Canada, as it is already commercially available.

The SASOL plant uses gasification followed by Fischer-Tropsch synthesis to produce a range of products. The process is flexible with respect

to the products, which are very pure relative to those from other coal-to-liquids schemes, but products may still not meet Canadian specifications. The plant produces an acceptable gasoline, but the diesel oil tends to be waxy and has poor low-temperature characteristics. Product quality can, of course, be improved my modified or extended processing, but this would only add to product cost, which would already by very high if such a plant were located in Canada.

These disadvantages have tended to discourage research on Fischer-Tropsch synthesis in Canada and the United States. Offsetting these are several advantages that could be significant in certain regions of Canada.

Because the primary conversion stage is a gasifier, the synthesis route can tolerate a wide range of coals. Of particular importance is acceptability of coals with up to 45% ash. Coals fed to SASOL typically contain 25-35% ash.

Problem areas

The basic approach in current liquids-from-coal R & D is to maximize the yield of premium products without resorting to extreme temperatures and pressures which lead to high costs. In most experimental plants there have been several recurring problems common to most processes.

In the more advanced processes, these are related less to the process itself than to basic mechanical engineering and auxiliary operations. As the processes approach commercialization, these problems begin to be measured in dollars, particularly as scale-up can aggravate them.

The problems are many, but some do currently stand out as being most significant. Some examples are given below.

Basic engineering - Hydroliquefaction processes use hot, high-pressure slurries. The handling and pumping of large quantities of such slurries is difficult. They are abrasive, and tend to plug equipment. Canada has extensive experience with mineral slurries, but not at coal liquefaction temperatures and pressures.

All hydroliquefaction processes produce residual solids consisting of ash and unreacted coal. Separation of these solids from liquid products can be very difficult by conventional methods which have not been designed for the type of streams coming from a coal liquefaction process. The problem arises from the presence of very finely-divided solids in heavy, viscous liquids. Several separation techniques have been tried, the most promising of which are

distillation and solvent extraction.

High temperatures and pressures, and the nature of the liquids handled in coal liquefaction processes, create harsh environments that lead to corrosion and erosion of vessels and piping materials. Processes that use hydrogen face the problem of the hydrogen reacting with certain steels, leading to cracking. Other chemicals, such as carbon monoxide, may present similar problems, but knowledge of these is limited. Because such environments are also encountered in processes like bitumen hydrocracking, development of improved materials of construction will be an important area of research for Canada.

Hydrogen supply - Hydrogenation, whether for coal liquefaction, bitumen upgrading, or petroleum refining, requires large quantities of hydrogen. Development of Canada's coal and petroleum resources will require increasing amounts of hydrogen, and costs and methods for its production are receiving serious attention.

Currently almost all the hydrogen used in Canada is made by steam reforming of natural gas, probably consuming about 5% of domestic gas production. There are several other ways to make hydrogen: steam reforming of naphtha and refinery off-gases, gasification of coal or liquefaction residues, and nuclear-assisted electrolysis. Currently, natural gas is in most circumstances the cheapest source, but further analysis may reveal that use of liquefaction residues could substantially improve plant economics, particularly as it would also reduce waste disposal requirements.

Feedstock quality and basic coal science - Experimental results at the bench and pilot scales often outpace fundamental process research in engineering fields. Fundamental studies usually help improve the process later. As the technology advances toward commercialization, seemingly minor improvements can make major financial differences.

This is the case in coal liquefaction, in which better knowledge of the effects of feedstock characteristics on product quality and process operability might improve yields and thermal efficiencies, reduce capital costs, and help avoid costly shut-downs. Such knowledge is necessary for a full evaluation of the suitability of Canadian coals for liquefaction. Of particular interest are the petrographic and chemical characterizations of the coals, of which knowledge is superficial.

Environmental impact - Commercial coal liquefaction facilities would be expected to undergo environmental impact assessment before approval. The subject has to date received little attention. The impact of the mining operation itself is common to all utilization routes and will not be discussed here.

The principal emissions of concern are large quantities of gaseous, liquid and solid effluents, as well as waste heat, although undesirable noise and odours are also produced. Gaseous and liquid emissions could probably be dealt with by conventional means employed in petroleum refineries.

Even more important in the Canadian context is the large water requirements, which might prove insurmountable. In certain areas in Western Canada where water is not plentiful. Based on energy output, and depending on the processes used, a coal liquefaction plant might be expected to use two to four times as much water as an oil refinery, but less than 25% as much as a coal-fired or nuclear power station. An oil sands plant based on surface mining would consume about 50% more water than a coal hydroliquefaction facility of equivalent size.

Principal technological uncertainties

The lead time available to Canada should permit development of a research capability and infrastructure that could evaluate the many aspects of the liquids-from-coal option to ensure that decisions are made with as sound an information base as possible.

Identifying technological uncertainties amounts to asking "What don't we know?" and therefore leads to an endless list. However, a number of recurring subjects have surfaced in researching efforts in Canada and elsewhere. Thus it is possible to identify the following as the principal concerns that are ripe for immediate study, but these are not necessarily given in the order of importance:

1. assessment of the suitability of Canadian coals for liquefaction, deposit by deposit, particularly where other utilization routes are also being considered; this would include consideration of deposit size and environmental factors;
2. process studies to develop technology especially well-suited to domestic coals;
3. chemical, physical and petrographic characterization of Canadian coals, and ways in which these affect behaviour in liquefaction processes;

4. technical and economic assessment of ways in which coals can be used to improve liquid yields from oil sands and heavy oils;
5. relative economic evaluation of hydrogen production processes in the context of natural gas strategy;
6. fundamental studies of the chemistry of coal-derived liquids, to determine properties and identify problems associated with specific end uses;
7. development of improved catalysts for catalytic processes;
8. mechanical and design engineering on such problems as the handling of coal and coal-in-oil slurries, and solid-liquid separation;
9. research on improved materials for the harsh environments to be expected in coal, bitumen and heavy oil processing;
10. investigation of the environmental impacts of coal liquefaction facilities, preferably site-specific, including health hazards presented by the products and compatibility with existing and projected government regulations;
11. economic projections to determine need for the full range of coal-derived fuels in the Canadian market.

COAL-OIL-MIXTURE PROJECTS

New Brunswick Electric Power Commission

The New Brunswick Electric Power Commission COM project is essentially a feasibility study being conducted in a small power station boiler. The initial phase of the project which began in October 1977 has been described by Jeffries etal.(4) The plant selected for the project is located at Chatham, New Brunswick and comprises two small units of 12.5 MW and 21 MW with the former being used for the COM project. Due to the age of the plant and its relatively small size, it is ideal for research purposes since it is not normally operated because of power generation economics. This stand-by situation allows ample time for the modifications and test operation without being constrained to supply power to the grid. The unit selected is a Foster Wheeler three drum type supplied in 1945. It is designed to generate 140,000 lb/hr of steam at 605 psig and 835^{o}F from feedwater at 350^{o}F. The combustion chamber is reverse fired in which the hot flame gases recirculate back along the side walls before entering the boiler tube tanks. The boiler is designed for either coal or oil firing, consequently boiler modifications to permit COM firing will be minimized. The modifications to the fuel supply system

have been made so that the COM supply system is in parallel with the existing heavy fuel oil supply to allow for rapid change over in case of an emergency or standby power demand.

In the COM preparation system, the coal is fed from the bunker into the mill where it is pulverized to PF fineness, 80% through 200 mesh. A cyclone separator then separates the coal and primary air, the latter being passed through a baghouse to collect the coal fines, which may then be returned to the COM blender. From the cyclone separator the coal is gravity fed via a rotary screw feeder into the COM blender. Initial mixing of the COM is achieved by direct contact of the incoming supply of heavy fuel oil and coal from the coal feeder. Some preliminary coal wetting is achieved by an oil spray located above the incoming coal feed. The slurry for firing at the boiler is extracted from the blender via a recirculation line which is necessary to prevent the settling out of coal at low flow rates or when the boiler is shut down. Provision is made for steam purging of all COM lines supplying the burners and the return line to the blender.

The objectives of Phase I of the program:

1. To demonstrate a coal/oil slurry comprising Minto NB coal and a typical heavy fuel or No.6 fuel oil can be effectively burned.
2. To investigate environmental emissions and fly ash distributions
3. To ascertain whether simple mechanical mixing of coal-in-oil gives a COM which is suitable for power plant operation.
4. To investigate the heat transfer characteristics of the furnace when firing coal/oil slurry and coal and oil separately.

Phase II of the project which began on April 1, 1978 will extend the range of coal contents studied up to 40% by weight. In addition, the COM preparation system will be changed to include the National Research Council of Canada (NRCC) coal benefication process which has the capability of substantially reducing the ash content and halving the sulphur content of the Minto NB coal. (5).

Ontario Research Foundation Project

This project is a study of the combustion and emission characteristics of coal-oil mixtures in a research tunnel furnace. In addition to investigating the combustion and emission characteristics of COM's the

Ontario Research Foundation (ORF) will examine potential fouling and slagging problems usually associated with the combustion of low grade coals. The project is aimed at the introduction of new and improved technology to COM combustion both to optimize fuel efficiency and to reduce levels of pollutant emissions.

The following stages will be carried out leading to the COM combustion trials which have now been completed.

(i) Coal Selection and Preparation

The selection of suitable coal will be made by the project co-sponsors. Coal samples will then be obtained for analysis, grinding, benefication and agglomerate production and COM stabilization.

(ii) Coal-in-Oil Mixture Preparation:

The NRCC process produces agglomerates, these will be blended into a stable COM by the hydroshear process. Relevant physical properties of the COM will be determined.

(iii) Burner and Furnace Modifications and Combustion Performance Evaluation

The test facility at the Ontario Research Foundation can handle burners of up to 20×10^6 Btu/hr capacity. It is currently equipped with the high-intensity burner which has been selected for part of the COM combustion trials. The co-sponsors will select a conventional burner that is widely used in Canada for comparative purposes. During the performance tests and exploratory trials, detailed an ysis of flue gas emissions, CO, CO_2, NO_x, SO_2, O_2 and particulates will be made using conventional monitoring techniques. The combustion performance of each burner both on No.6 fuel oil and a range of COMs containing from 0 - 50% by weight of coal will be investigated. Any slagging or fouling problems not usually associated with oil firing will be studied, particularly with COMs of high coal content or containing coal of high ash content.

The Steel Company of Canada Limited (Stelco)

The project which is entitled "Development of Coal-Oil Slurry Fuels for Blast Furnace Injection" was scheduled to begin on April 1, 1978. Oil injection into blast furnace tuyeres is not a new idea, with improved yield,

blast furnace fuel savings and a reduction in the use of metallurgical coke being the major benefits. The aim of this project is to develop a slurry injection system which will use coal, coke oven tar, oil bottoms and creosote. The coke oven tar is a novel feature of the project and is attractive because of its availability in a steel works. The main objectives of the project besides the design of the slurry injection system are to find out the ability of the COM to displace fuel oil and natural gas in blast-furnace.

Activity on this Project has Fallen into Four Main Categories During 1979

1. A study of coal in oil handling has been completed. The objectives of the study were to define the most suitable pumping equipment and the transmission pressure drop characteristics of a series of coal in oil mixtures. The data developed in this part of the program is intended to be used as design data in subsequent phases of the program. It was also used in the design of the system used in the combustion experiments.
2. A combustion study of coal in oil mixtures has been completed. An experimental unit comprising of fuel handling system (15-120GPH) an air preheat system (1800^{o}F) and a combustor was designed and built for the program. The combustor consisted of a Tuyere injecting into a 3M x 1M furnace with provision for flame measurement at ten locations downstream of the Tuyere. The measurement capability therefore extended beyond the boundary of the blast furnace raceway. Over 50 individual flames have been assessed in this system. These flames reflect combinations of one coal in three carrier fluids, two load levels, three coal size distributions and three coal concentrations. These combustion trials have established a number of coal in oil mixtures that are considered acceptable for use as a blast furnace injectant.
3. A design study for three tuyere blast furnace trial incorporating the results from the combustion study described above. This is based on the optimum coal in oil mixture.
4. A preliminary design cost study based on the optimum coal in oil mixture defined in the combustion studies is currently in progress. This will define at an approximate level, the cost of a complete blast furnace conversion to coal in oil and the subsequent operating costs.

ACKNOWLEDGEMENTS

This presentation is based on the work of many staff members of the Energy Research Laboratories of CANMET. It owes a special acknowledgement to Mr. G. Taylor, Dr. H. Whaley and Mr. N. Banks.